ForceWorks

Teacher's exhibition notes

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ScienceWorks and The Observatory Science Centre are part of Science Projects, an educational charity specialising in the communication of science through hands-on exhibits.

MAGNETS

Forces can be exerted without direct contact between objects under certain conditions
Magnets have 'North' and 'South' poles

DESCRIPTION

LEFT; There are a pair of large magnets which repel each other, and another identical pair arranged so that they attract. The magnets are arranged on rods so that if they are moved closer together they do not twist or slide out of the way.

RIGHT: There is a group of large magnets at the centre of a table which can be turned around it. On this are strung two different magnets, and two small metal rods of different materials, which respond to the field of the central magnets.

Plates of different materials can be tested for their response to the magnets.

CURRICULUM LINKS

Key stage 1
"...forces should be experienced in the way they push, pull, make things move..."
Key stage 2
"Pupils should explore different types of forces...They should be introduced to the idea that forces act in opposition to each other..."
Key stage 3
"Pupils should discover that forces can act to...begin to move or stop [things]..."

RELATED EXHIBITS

Magnetic pendulum
A magnet on a pendulum can be swung above other magnets to which it responds. A tray of iron clippings can be placed on top of a magnet to see its magnetic field.
Resolution
Investigates the net effect of forces which act in different directions on one object.

WHAT TO DO

LEFT: Push the large round magnets along the rods and feel the forces.

Q: Why is one pair attracted to each other and the other repelled?
(A: One pair has a 'North' side facing a 'South' one and 'unlike' poles attract. The others, with 'like' poles facing, repel.)

Q: When does the force feel strongest and weakest?
(A: When the magnets are close together it is strong and weakest when further apart. The change is gradual.)

Q: What is the effect of a sheet of material between the magnets on the strength of the forces?
(A: Most have no effect. Only iron does because both magnets are attracted to it.)

RIGHT: Move the small objects on the turntable close to the central magnets.

Q: What happens to the objects?
(A: Some are suspended in 'mid-air', by the combination of magnetic attraction and the string's tension. Only the magnets and one metal are attracted to the magnet.)

Q: Turn the table slowly. What happens?
(A: The small magnets flip as they near a new face of the central magnets because these have their north and south faces arranged alternately - one face is north, the next south, etc.)

Q: Why do the objects float in the air?
(A: Magnetism is a vastly greater force than gravity.)

MORE THINGS TO DO

Test which of the rods attracted to the central magnets is itself a magnet by using the iron sheet.

MAGNETS: FURTHER INFORMATION

Magnetic force

Magnets are intriguing because the magnetic force is very strong and is easy to feel. Magnets attract other materials such as iron or steel. They also attract or repel each other.

A bar magnet has a north or south pole at its ends. Two similar poles repel each other but a north and south pole attract. Ring magnets have north or south poles on their opposite faces. The force is only felt over a relatively short distance and is strongest close to the magnets. (The force is inversely proportional to the square of the distance.) The magnetic force is not affected by paper or many other materials and it passes straight through as though they were not there. The only material to have any effect is iron which is attracted to the magnets.

At close distances the magnetic force is much stronger than gravity and a magnet can easily pick up a small object such as a paper clip.

The turntable experiment shows how the magnetic force is also strong enough to suspend small magnets in mid-air. The magnet flips over as each north and south pole comes into view but the iron rod is attacted to the magnet regardless of which pole it sees.

Separating materials

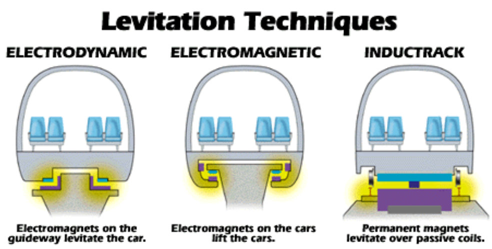
Magnets can be used to tell the difference between iron, steel and other metals -- this can be used when recycling materials. Try testing pennies for their response to a magnet to seee what they are made of.

Electromagnets

Many magnets are permanent but some can be turned on and off using an electric current. These are called electromagnets - they are not dealt with in this set but one can be found in ElectricityWorks.

Magnets & gravity

A magnet can hold another magnet in the air or lift a piece of iron or steel. This is because magnetic force is dramatically greater than the force of gravity. Compared with the other fundamental forces - weak and strong nuclear forces and electromagnetic force - gravity is very weak. All objects exert gravitational pull on one another but the force is so miniscule that it is not apparent. It is only the huge mass of the earth and other celestial objects that produce a force of significance. Magnets are used to levitate Maglev trains.



SPINNING TOPS

To spin well, tops need evenly distributed weight The diameter and weight of a top makes a difference to how easy it is to spin, and how long it spins for

DESCRIPTION

Several spinning tops are provided which can be spun by hand. They vary in diameter and thickness. Small weights can be fitted to the tops in different positions by velcro so they can not be thrown off when the top is spun. Pupils can investigate the effect of the different weights on the spinning of the tops.

CURRICULUM LINKS

Key stage 1

"Pupils should have early experience of devices which move...forces should be experienced in the way they...make things move...stop things..."

Key stage 2

"They should explore friction, and investigate the ways in which the speed of a moving object can be changed by the application of forces. This work should be set in everyday situations, for example...balancing systems".

Key stage 3

"Pupils should investigate turning forces and the centre of mass in solid objects, the stability of everyday objects...".

RELATED EXHIBITS

Centre of gravity

The centre of gravity of various shapes, some with off-centre weights attached can be investigated.

Balance

Pupils can balance objects, showing the importance of weights, and their distance from the pivot.

WHAT TO DO

Take any weights off the tops and try spinning them.

Q: Which tops spin fastest?

(A: The smaller ones.)

Q: Which tops are hardest to spin?

(A: The heavy discs with two layers are more difficult to spin fast.)

MORE THINGS TO DO

Stick a weight onto one of the tops.

Q: What differences does this make?

(A: The top becomes very unbalanced and cannot be spun properly.)

Add two weights, one on each side of the top and near the edge.

Q: What differences does this make?

(A: The top becomes better balanced when spinning.)

Q: Compare spinning the top with two weights in a well balanced position, with one with no weights at all?

(A: With the weights removed, the top is still well balanced and it is easier to spin it fast. But from an equal speed of spin, the un-weighted top will slow down and fall over sooner.)

SPINNING TOPS: FURTHER INFORMATION

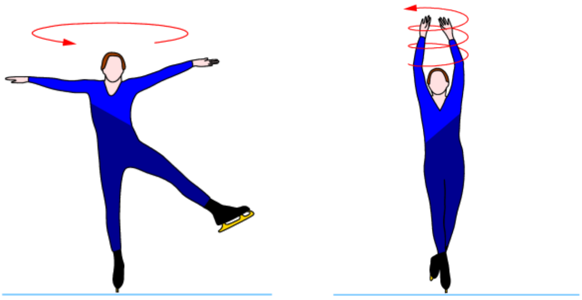
Twisting force

Forces can push, pull, squeeze and twist. It is the twisting force which makes the tops spin. To make it spin you have to apply all the force to the pivot. If the top is heavy then you have to use a lot of force to make it turn; it is easy to make a lightweight top spin fast. Eventually it will slow down and fall, because of the small amount of friction at its point.

If the weight is unbalanced the top will wobble and will not spin properly.

Speed of spin

How fast it spins also depends on where on the top the weight is positioned. The closer it is to the pivot the faster the turn. Imagine an ice-skater or a ballet dancer spinning, with their arms stretched out. They turn quite slowly but as they bring their arms close to their body they rapidly speed up.



For an object orbiting a central point or turning on an axis, angular momentum is the product of the object's mass times its distance from centre (or axis) times the velocity at which it orbits around the centre.

Some applications

Racing bike wheels have very light rims and tyres so they can pick up speed quickly. Flywheels work on the opposite principle with a heavy rim so although they take a while to get up to speed, they keep spinning for longer.

PRESSURE

The effect of a force can depend on the area over which it is applied.

DESCRIPTION
Various 'feet' shapes of different sizes with knobs are provided. They can be pushed into the foam rubber surface.

Pupils can feel the resistance of the foam rubber to shapes of different areas being pushed down.

CURRICULUM LINKS
Key stage 1
"...forces should be experienced in the way they push...and change the shape of objects".
Key stage 2
"They should be introduced to the ideas that forces act in opposition to each other...and that the relative sizes...of the forces can affect the movement of an object".
Key stage 3
"Pupils should discover that forces can act to change the shape of things. They should investigate how the effect of a force applied over different areas results in different pressures...".

RELATED EXHIBITS
See stress
This can show the differences in internal forces when the same force is applied on an object over a small area or a large one.

WHAT TO DO
Push the largest 'foot' into the foam, then do the same with the smallest one.

Q: Which 'foot' needs the greater force to push it down?
(A: The larger 'foot' is harder.)

Try again, pushing both down equally.

Q: Which 'foot' goes deeper?
(A: The smaller foot goes quite a lot further into the foam when pushed with equal force.)

Q: Is it the 'foot' length, width or both (the area) which makes the difference?
(A: The area.)

MORE THINGS TO DO
Push one of the 'feet' into the foam using your little finger only.

Q: What does your finger feel?
(A: It feels an increasing force pushing up, the deeper the 'foot' gets.)

Q: Push the 'foot' well down, then quickly let go - what happens?
(A: The 'foot' jumps up. As you push down, the foam pushes up with an equal force. Removing the downward force means the upward force is unopposed.)

OTHER THINGS TO DO
Think about trying to walk across deep snow, without sinking in.

Q: Which would be best - a shoe that's got a sole with a large or a small area?
(A: The large sole shoe would be best. It would spread your weight.)

Q: If you and someone lighter had the same size shoes on, which would sink deeper into the snow?
(A: You would!)

PRESSURE: FURTHER INFORMATION

Pressure is not the same as force
The words pressure and force are often mixed up in every day speech but they are not the same. Pressure is a measure of force per unit area.

When you push one of the foot shapes into the foam you are using a force. Pressure measures how much force you use spread over an area. If the force is spread over a big area then the pressure on the foam is less than if all the force was concentrated into a small area.

The more force you use to push the foot into the foam the further it will sink. But if the foot is big then the force is spread over a larger area and the foot will not sink in so far into the foam.

Some applications
This is the reason people in snowy areas wear snowshoes. When you walk on snow it is your weight that is the force. The large area of the snowshoes spreads out the force so the pressure on the snow is small. The snow is able to push back just enough to hold you up and stop you sinking in.

Similarly camels have large feet to help them walk across the desert sand.

This relationship between force and pressure can be seen in other ways too. A sharp knife cuts more easily than a blunt one because the force is concentrated in an extremely small area. Pushing a drawing pin into a board is possible for the same reason.

Measure of pressure
Pressure is a measure of force per unit area. Here is an example: A child weighing 30 kilograms exerts a downward force of 300 newtons. If she wore a pair of trainers with an area of 6000 square millimetres then the pressure on the floor is 300 divided by 6000, i.e. 0.05 newtons per sq. mm. Now imagine she wore a pair of stiletto shoes and balanced on one heel with an area of 30 sq.mm. The pressure is 300 divided by 30 i.e. 10 newtons/sq.mm., enough to make a dent in some floors (and someone else's foot!).

SKID TEST

Stopping distance of a vehicle is affected by its speed It is also affected by the surface it is travelling on

DESCRIPTION
A model car can be rolled down a ramp on to a flat area. It has simple front and back brakes, which are operated electrically by push buttons on the exhibit frame. The stopping distance of the car under various conditions is emphasised by a model zebra crossing at the far end.

The speed of the car can be controlled by the height at which it is released. The flat surface may also be turned over, revealing a different surface.

CURRICULUM LINKS
Key stage 1
“Pupils should have experience of devices which move....forces should be experienced in the way they push, pull, make things move, stop things...such experiences should include, for example, road safety activities”.
Key stage 2
“Pupils should explore friction, and investigate the ways in which the speed of a moving object can be changed by the application of forces. This work should be set in everyday situations, for example, road safety, transport...“
Key stage 3
“Pupils should discover that forces can act to...begin to move or stop [things]. This work should make references to friction and be related to...vehicular movement with particular reference to road safety. They should investigate how stopping distance is affected by speed”.

RELATED EXHIBITS
Resolution
Investigates the net effect of forces which act in different directions on one object.

WHAT TO DO
Turn the flat black area over so that the shiny (not rubber) side is uppermost. Place the car at the top of the ramp and release it.

Q: What happens if you don't press the brakes?
(A: The car rolls quickly right across the flat area.)

Q: What happens if you do press the brakes?
(A: The wheels of the car stop turning but the car slides across the flat area.)

Turn the flat black area over so that the rubber (not shiny) side is uppermost. Place the car at the top of the ramp and release it.

Q: What happens if you don't press the brakes?
(A: The car rolls quickly right across the flat area.)

Q: What happens if you do press the brakes?
(A: The car stops quickly.)

MORE THINGS TO DO
Try different combinations of front and back brakes to stop the car on each surface. See if the car can be slowed down without stopping the wheels turning (i.e. by pushing on the brakes more gently).

Q: Can the car be stopped more quickly by pressing on the brakes more gently or by 'pumping' them?
(A: This can work on the shiny surface.)

SKID TEST: FURTHER INFORMATION

Friction

Friction is an important force. It is the reason we are able to walk. When you take a step, you push backwards on the ground. Friction causes the ground to push back in the opposite direction so your foot stays put and your body moves forward. Imagine trying to walk with smooth-soled shoes on a slippery ice rink.

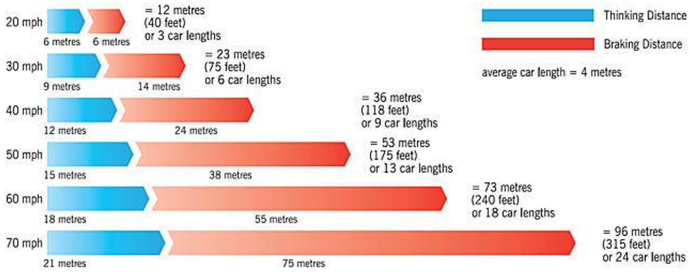
Shoes use materials which will not slip the ground. Car tyres are made of special rubber to increase their grip on the road. When the road is wet however the water acts as a lubricant and rubber would slip on it. Tyres therefore have treads cut into their surfaces so that the water is squeezed into the grooves and away from the contact area between rubber and road.

The road surface will also vary in its friction quality. Different materials and textures can be used. The best surfaces are the most expensive and are often only used in special places, such as junctions or pedestrian crossings. When roads get worn the surface becomes smoother and less able to grip and vehicles can skid on it. Rain obviously makes the most difference but the oily deposits left by cars can affect it too. Particularly when it is raining after a period of drought, a mixture of oil and water gives a very skiddy surface.

Stopping

Friction helps things move but it also helps them stop, too. Cars and bicycles use brakes to slow down — the brake pads press against the wheel with a large force to get a large amount of friction. If the brakes are worn smooth or not pressed on hard enough, the vehicle will take longer to slow down. If you press too hard the brakes will lock on, the wheel will stop turning suddenly and then skid across the road.

The faster a vehicle is moving the longer it will take to stop. The Highway Code gives stopping distances likely at given speeds.



SEE STRESS

Forces have an effect inside an object.
The way an object responds to forces exerted on it depends on its shape.

DESCRIPTION
The exhibit consists of two pairs of screens. The rear ones are illuminated and the front ones are transparent.

Transparent plastic objects are provided which can be squeezed, bent, twisted, etc. whilst holding them between the two screens. Vivid colours and patterns can be seen inside the object, indicating the stress within the object, being created by the forces put on it. The stress varies according to its shape and thickness and to the degree of squeezing, etc.

CURRICULUM LINKS
Key stage 1
"...forces should be experienced in the way they push, pull...change the shape of objects."
Key stage 2
"Pupils should explore different types of forces...to compare their effects in, for example...bridge building. They should investigate the strength of a simple structure."
Key stage 3)
"Pupils should discover that forces can act to change the shape of things. They should investigate how the effect of a force applied over different areas results in different pressures...this work should relate to the design and evaluation of structures, for example, bridges..."

RELATED EXHIBITS
Pressure
The exhibit shows the effect of forces downwards onto foam rubber, producing changes in its shape.

WHAT TO DO
Hold the shapes behind the front screen. Squeeze, bend or twist them.

Q: What do you see?
(A: Different colours, sometimes in striped patterns, indicating stress.)

Q: What happens to the stripes of colour when you squeeze/bend/twist harder or softer?
(A: The stripes get closer together under greater force, further apart with less.)

Q: When you see stripes of colours, describe the parts of the shape where they are closest together?
(A: Around sharp corners and narrow parts.)

Q: Is the material stressed when being squeezed, stretched or both?
(A: Both.)

MORE THINGS TO DO
Push down gently on one of the objects first with the sharp end of a pencil, then with the flat end. Try to push down with equal force.

Q: What differences do you see in the colours produced?
(A: With the sharp end of the pencil, the coloured stripes are more vivid and closer together. The sharp end concentrates the same force on a smaller area than the flat end. The greater the pressure - the greater the stress.)

Turn the polaroid sunglasses through 90 degrees.

Q: What do you see?
(A: In one plane you can see through them; in the other they will appear black. This is how this type of sunglasses reduces glare.)

SEE STRESS: FURTHER INFORMATION

Stress
A force can be used to squeeze or twist objects. Soft objects will change shape a lot but stiffer ones will resist the force.

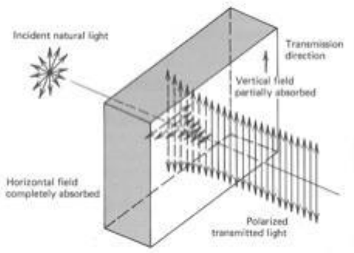
Usually it is impossible to see the forces inside an object but polarised light can help reveal them in transparent materials. The forces shown as a pattern of brightly coloured lines. If the lines are close together there is more force - or stress - at that point. This shows up best at sharp corners or the marks where it is easy to see how much stress is concentrated.

All materials are subject to stress**.** Different ones behave differently, but in general greater stress is built up at certain points, such as sharp corners, holes and deep marks.

Some applications
Ships and bridges have been known to break up due to stresses built up around such points. Aircraft are particularly subject to huge forces when flying and a great deal of research has to be put into their design to prevent metal fatigue happening and causing catastrophic failure.

Some of the materials shown here such as polycarbonate are used in crash helmets. If they get scratched or stressed, they no longer have the strength required in a crash. Even painting them can reduce their resistance.

Polarised light
The stress is made visible by viewing with light that is polarised by special sheets. These allow light in only one plane to pass through them. This material is used in some sunglasses to reduce glare. If you hold two pairs of polaroid sunglasses at right angles to one another, you can not see through them. You can do in this exhibit by turning the dark glasses between the screens.



CENTRE OF GRAVITY

The centre of gravity is the point at which an object can balance with only one support
The centre of gravity determines an object's stability

DESCRIPTION

LEFT: A collection of shapes, some with weights attached can be pivoted on a post. It is possible with most of them to find the point at which they balance which may not be the centre of the shape.

RIGHT: There are two pairs of objects. Two mushroom-shapes each contains a steel ball, whose high or low position is visible. Pupils can examine its effect on the stability of the objects. There is also a pair of red buses with high or low weights which can not be seen. They can be tilted till they fall over.

CURRICULUM LINKS

Key stage 1

“They should experience the natural force of gravity pulling things down...”

Key stage 2

“Pupils should explore different types of forces including gravity... This work should be set in everyday situations, for example ...balancing systems...”

Key stage 3

“Pupils should investigate turning forces and the centre of mass in solid objects, the stability of everyday objects...”

RELATED EXHIBITS

Balance

This exhibit provides opportunities to balance objects, showing the importance of the weight distribution and of its distance from the pivot

WHAT TO DO

LEFT: Balance the shapes on the post.

Q: Is the balance point in the middle of any of the objects?
(A: Simple geometric shapes without weights have central balance points.)

Q: Is the balance point not in the middle of any of the objects?
(A: Yes. Objects with weights have their balance point nearer the weights.)

Q: Are there any which can’t be balanced?
(A: Yes, because the centre of gravity of the object is not in the object at all. A 'polo' shape is an example.)

Balance in turn some shapes with weights underneath, some with weights on the top and some with no weights. Rock them.

Q: Which ones fall off most easily?
(A: The shapes with weights underneath are easier to balance. The centre of gravity is below the balance point, making it more stable. When the weight is above it is much less so.)

RIGHT: Try to get the mushroom-shapes to stand upright on their round bottoms.

Q: Which can be stood up and why?
(A: The one with the ball at the bottom will always stand upright because its centre of gravity is below the critical point. The one with the high ball can not, because of its high centre of gravity.)

Tilt the ‘buses’ over in front of the scale.

Q: Can one be tilted further before it falls?
(A: Each bus contains a weight in either a high or low position. When it is low it can be tlted further before it falls.)

CENTRE OF GRAVITY: FURTHER INFORMATION

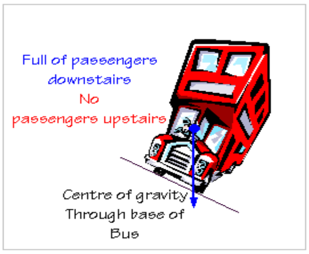
Gravity
Gravity is a force, first dicovered by Newton. It pulls everything down to the ground. In fact all objects attract each other but the more massive ones have the greatest attraction. The Earth is so big it attracts all objects to it. But the sun is much bigger still and attracts the earth to it, which is what keeps it in orbit around itself.

Things can be propped up to stop them falling. Think of a book on a table - gravity is still pulling it down, and only the upward force provided by the table keeps it in place. The book is stationary so the forces must exactly balance out.

Centre of gravity
Propping something up on a single point is difficult. You have to locate the exact balance point - called the centre of gravity. On a flat disc or other regular shape the centre of gravity is in the middle. But if the shape is irregular or the weight is uneven then it is more difficult to find. For some shapes the centre of gravity is outside the shape. A simple example of this is a ring, where the centre of gravity is in the middle. (Note - a ring can be balanced but only with difficulty, by standing it on its edg

Some applications
Having a low centre of gravity is an advantage when trying to balance. Trick-cyclists on a wire stretched across a ravine use a weight hanging below their bike so the centre of gravity is below the wire making it very difficult to fall off. Although they do not look it, the low slung bike where the rider sits back low down between the two wheels is more stable than the conventional one.

Double-decker buses
Tall vehicles like buses are designed with a very low centre of gravity. Imagine what would happen otherwise if the passengers on the top deck all rushed over to one side to see a celebrity!



RESOLUTION

By applying forces in three different directions it is possible to move an object in any direction
Equal forces in opposite directions cancel each other

DESCRIPTION

RIGHT: Inside a clear case is a red pointer with three strings attached to it. Each string can be pulled using a knob which will cause it to move,in that direction. By pulling on the other strrings at the same time, the object in the case can be made to follow various tracks which are also provided.

LEFT: A pointer, like a hand on a clock, hangs vertically. It has three springs attached to on each side. Each spring can be pulled moving the pointer to a new position. The effect is that of a force adding machine and shows how forces in opposite directions cancel each other out.

CURRICULUM LINKS

Key stage 1
"Pupils should have early experience of things that move."
Key stage 2
"Pupils should...be introduced to the idea... that one force may be bigger than another, or equal to it, and that the relative sizes and directions of the force can affect the movement of an object."
Key stage 3
"Pupils should...discover that forces can act to change the shape of things, to begin to move or stop them.."

RELATED EXHIBITS

Direction of forces
The importance of the direction in which a force is applied can be investigated.
Balance
Shows how several forces can act at the same time to produce one net effect.

WHAT TO DO

RIGHT: Slowly pull one of the knobs attached to central pointer by string.

Q: What happens?
(A: The object moves out along the line of that string.)

Pull two of the knobs out at once.

Q: Which direction does the pointer move?
(A: Somewhere between the directions of the two strings, depending on which one is being pulled the hardest.)

Pull all of the knobs out the same amount.

Q: Where does the pointer go?
(A: Nowhere. Although there are three forces on it they cancel each other out.)

MORE THINGS TO DO

Place a disc onto the middle and try to get the pointer to follow the track.

WHAT TO DO

LEFT: Pull two springs out to the left.

Q: How many springs on the right should you pull to cancel the effect?
(A: Two.)

Release one of the springs on the right.

Q: Where does the pointer point and why?
(A: One to the left. The one right spring has cancelled the effect of one of the two left springs, leaving the pull of only one spring.)

MORE THINGS TO DO

Try having one person on the left and one on the right, each concealing the springs on their side. Each then pulls out some springs. From the final position of the pointer they try to guess what the other person did.

RESOLUTION: FURTHER INFORMATION

Forces in opposition
If something is not moving it does not mean there are no forces acting on it, just that all the forces.

Everything on Earth is under the influence of the force of gravity and we are either falling to the ground (which we do occasionally) or being supported by an equal and upward force from whatever we are resting on.

Resolution
Other forces can also balance out. In a tug-of-war both sides may be pulling as hard as possible but neither side moves. Or when trying to open a stuck jam jar lid your twisting force is exactly countered by the equal force of friction. Only when forces are unbalanced do objects start to move.

Forces can be added up. When they are in line this is easy - two pulls to the left minus one pull to the right equals the same as one pull to the left.

When the forces are not in line, then the maths is more complicated and the details are beyond the curriculum for primary school children. But this exhibit allows it to be done in a direct way. The three strings can be pulled and the forces all add up to move the pointer in any direction. If each is pulled by exactly the same amount of force the pointer will remain stationary.

Several other exhibits show the balance of forces. For example, in the Magnets exhibit the force of the magnets in the centre of the turntable balance the force of gravity, holding the small magnets in mid-air.

DIRECTION OF FORCES

The direction of a force is very important.
If something is only free to move in one direction any part of a force not in that direction won't help it move.

DESCRIPTION
LEFT: A 'drawbridge' can be lifted by pulling on any one of four knobs attached to strings which come through the 'castle wall' at different heights. They are all attached to the 'drawbridge' at the same place, therefore each one offers a different angle of pull.

RIGHT: A crank consists of a wheel which is connected to a slider by a connecting rod. This can be fitted onto the wheel at one of three places. Arrows on the wheel and the connecting rod shows in the direction of movement. Moving the slider back and forth makes the wheel rotate.

CURRICULUM LINKS
Key stage 1
“Pupils should have early experience of things which move.”
Key stage 2
“Pupils should be introduced to the idea that...the relative sizes and directions of a force can affect the movement of an object.”
Key stage 3
"Pupils should investigate the effectiveness of simple machines..."

RELATED EXHIBITS
Resolution
An object responds to pulling forces in three different directions.

WHAT TO DO
LEFT: Pull each of the knobs in turn to lift the drawbridge.

Q: Which one lifts it most easily?
(A: The top one)

Q: When it first starts moving roughly in which direction is the end of the drawbridge going?
(A: Upwards.)

Q: How hard and how far you have to pull on each knob?
(A: Though each lifts the drawbridge the same distance the easiest moves furthest.)

Compare the angles between the strings and the drawbridge.

Q: Do any of the strings go exactly upwards?
(A: No.)

Q: Which is closest to going upwards - has the largest upwards component to its direction?
(A: The top one.)

RIGHT: Fix the connecting rod into one hole in the wheel. Use the slider to start turning the wheel when the arrows are at different angles to each other.

Q: When can't you turn it?
(A: When the arrows are at right angles to each other. No part of the rod's push is in a direction that point on the wheel can go.)

Q: When is it easiest to turn?
(A: When the arrows are lined up. The rod is now pushing in the same direction as that point on the wheel can move.)

OTHER THINGS TO DO
Think of devices which use up and down motion to create circular motion or vice-versa.

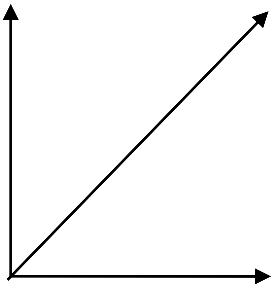
DIRECTION OF FORCES: FURTHER INFORMATION

Components of a force

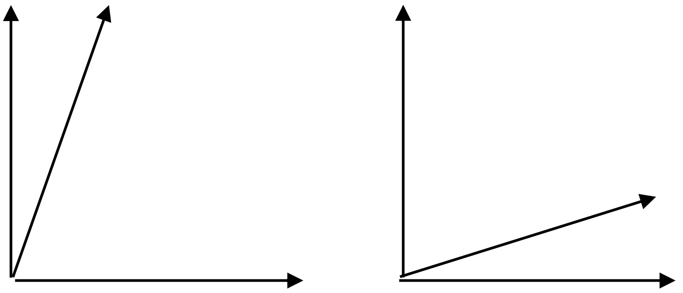
Some forces acting on an object can have more than one component. The effect will depend on the strength and direction of those components.

With the drawbridge you can see the difference in the force required to lift the bridge,depending on the angle of pull. Each of the strings has a different degrees of vertical and horizontal direction. The greater the vertical component, i.e. higher the string, the easier it is to lift, but the further you have to pull.

vertical
component line of pull



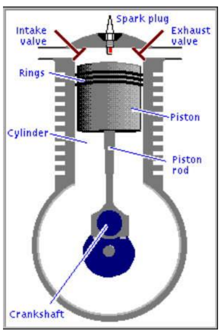
horizontal component

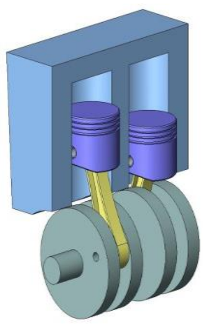


difficult easy

The crank

The crank wheel shows how reciprocal motion (up and down or back and forth) can be converted into rotary motion (circular) and vice-versa. An important application of this is in a car engine. Pistons are used to convert up and down movement produced by the fuel explosion in the combustion compartment into the circular motion of the crankshaft and thus the wheels. Similarly when the engine is started the rotation of the starter motor causes the pistons to move up and down, creating the sequence of "suck, squeeze, bang and blow" that is the internal combustion engine.





BALANCE TABLE

Objects balance if all the turning forces on it cancel out
The centre of gravity is the point at which an object can balance with only one pivot

DESCRIPTION
LEFT: Each of three different balance beams is balanced by moving its centre of gravity to a point above the pivot. This can be done by either shifting the position of the beam or adding weights to the beam.
RIGHT: A balance-table in the shape of a three-leaf clover is free to rock on a central pivot. It is unbalanced by a small weight fixed to one leaf of the table. Placing other weights on the table can cancel out the effect of this weight and make the balance level. A spirit level at the centre of gravity shows when this has been done.

CURRICULUM LINKS
Key stage 1)
“Pupils should experience the natural force of gravity pulling things down...”
Key stage 2
“Pupils should...be introduced to the idea... that one force may be bigger than another, or equal to it, and that the relative sizes and directions of the force can affect the movement of an object.”
Key stage 3
“Pupils should investigate turning forces and the centre of mass in solid objects.”

RELATED EXHIBITS
Centre of gravity
The centre of gravity of various shapes, some with off-centre weights attached can be investigated.

WHAT TO DO
RIGHT: Place the weights on the balance table and observe each one's effect. Try to balance the table with the bubble in spirit level exactly in the middle.

Q: What happens if you try to do this with just one weight?
(A: It is difficult because it is hard to find a position for one weight which exactly opposes the fixed weight -- it has to be opposite it and close to the pivot.)

Q: What happens if you try to balance it using two weights of the same size?
(A: You need to put one on the two free arms, each the same distance from the centre.)

Q: Can you balance the table using a big weight and a small weight?
(A: You need to have the smaller weight further from the central pivot.)

Q: Can the table be balanced with any number of weights?
(A: As long as they balance out, any number can be used.)

LEFT: Try to find the balance point of the two beams with fixed weights.

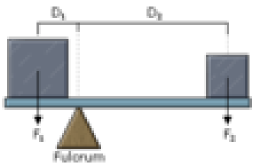
Q: Why is it near the end of one beam and in the middle of the other?
(A: One beam has most of its weight at one end. The weight of the other is evenly distributed along its length.)

Q: Can you balance the beam with the ball bearing?
(A: It is almost impossible as the ball keeps rolling about, shifting the centre of gravity.)

BALANCE TABLE: FURTHER INFORMATION

The Principle of moments

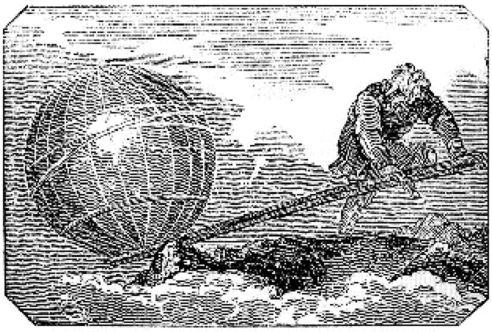
When a force acts at some distance from a point, and at an angle to it, then it has a turning effect.
On a see-saw, for example each child provides a turning effect in an opposite direction from the other. The weight of the child and the distance from the pivot determines the size of this turning effect and it soon becomes obvious to children that a large child near the pivot has the same effect as a small child further away. The force (in this case weight) multiplied by the distance from the pivot will be the same at each end if the see-saw is in balance. This is the principle of moments.



In the exhibit the closer the weight is to the pivot point the less effect it has. On the table this can be done by moving the weight, on the beams by shifting the pivot.

Levers

The same can be seen when using a lever. A small force at a long distance from the pivot can lift a heavy weight. "Give me a firm enough spot on which to stand and a long enough lever) and I will move the earth" as Archimedes is reputed to have said.



PULLEYS

Pulleys can reduce the force needed to lift or move weights

DESCRIPTION
Three identical springs are fixed to a frame and can be stretched by pulling three cords. Each cord is attached to a different pulley arrangement. The first cord passes direct to the knob without any pulley. The second cord passes round one pulley and the third cord passes round two pulleys.

CURRICULUM LINKS
Key stage 1
“...forces should be experienced in the way they push, pull, make things move..."
Key stage 2
"They should investigate the ways in which the speed of a moving object can be changed by the application of forces."
Key stage 3
"Pupils should investigate the effectiveness of simple machines..."

RELATED EXHIBITS
Direction of forces
This exhibit also shows the relationship between distance moved and the amount of force required.

WHAT TO DO
Pull each of the three knobs in turn.

Q: **Which one is easiest to pull?**
(A: The cord that passes round two pulleys.)

Q: **Which one do you have to pull furthest?**
(A: The cord that passes round two pulleys.)

Q: **Is there a connection between the last two experiments?**
(A: Pulleys reduce the force needed to lift an object or stretch a spring but they increase the distance you have to move.)

MORE THINGS TO DO
Try to measure the distance you have to move each knob.

Ask the class which work they prefer to do -- easier work for longer or harder work for a short time.

Relate how these pulleys work to the principle of levers - the greater the length of the lever the easier it is to move but the greater the distance required to do so.

PULLEYS: FURTHER INFORMATION

Pulleys
Pulleys can change the direction of a force. For instance with a simple pulley you still have to use the same effort or force to lift the weight but now you pull downwards to lift the weight upwards. Most people find this is much easier to do. But the real advantage comes in using more than one pulley.

With two pulleys the amount of force required to lift the load is halved - but you have to pull the rope for twice the distance. The same overall effort is required to lift the load. You can observe this very well with the exhibit, in trying to stretch the springs. (Of course here you are pulling sideways to the spring.)

Compound pulleys
Adding more pulleys reduces the force required even more. The reduction is equal to the number of pieces of rope joining the two sets of pulleys attached to the load. In practice friction starts to become significant if too many pulleys are used.

Ships pulleys
Raising sail on a ship requires the use of great force particularly in high wind. Pulleys are used to reduce the effort required. While simple pulleys were around before the record of history, the compound pulley is thought to have been invented by Archimedes. It was Marc Brunel (father of Isembard Kingdom Brunel) working for the Royal Navy at the Portsmouth Dockyard during the Napoleonic War who developed one of the earliest uses of mass production (book printing wa probably the first). The parts of the wooden blocks were made seperately to exact specifications and assembled, every part being able to fit with every other. Ten men were able to produce 160,000 per year.

Levers
The relationship between force and distance is similar to that in levers. In both cases they allow a small force to move a heavy weight. But you need a long lever or a long rope. (See Balance Table.)

MAGNETIC PENDULUM

Forces between objects can be exerted without direct contact under certain conditions
Magnets create fields of force around them

DESCRIPTION
LEFT: A pendulum with a magnet. is suspended above two movable discs which also contain magnets. The pendulum magnet can be swung across them and it responds to their repelling forces, in a chaotic manner.

RIGHT: There is a fixed disc with a large bar magnet. A clear tray containing wire clippings can be placed on top to show the shape of its magnetic field.

CURRICULUM LINKS
Key stage 1
"...forces should be experienced in the way they push, pull, make things move..."
Key stage 2
"Pupils should explore different types of forces...They should be introduced to the idea that forces act in opposition to each other..."
Key stage 3
"Pupils should discover that forces can act to...begin to move or stop [things]..."

RELATED EXHIBITS
Magnets
Magnets can be arranged to demonstrate the forces of attraction and repulsion.

WHAT TO DO
LEFT: Swing the pendulum magnet gently to and fro above the magnets in the discs.

Q: What happens to the pendulum?
(A: It swings erratically.)

Q: Why is this?
(A: The magnet in the pendulum has a pole facing downwards which is repelled by the magnets, whose similar poles are facing upwards.)

Q: Is it possible, knowing the forces involved, to predict the position of the pendulum?
(A: It is impossible to be precise about its movement. This is known as chaos. Other systems such as weather work in this way.)

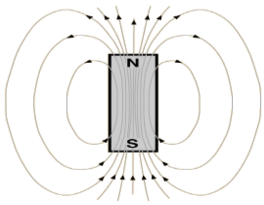
RIGHT: Place the tray of green clippings on top of the long bar magnet in the red disc fixed to the table.

Q: What can you see?
(A: The green clippings take a particular shape. It is roughly the same shape every time.)

Q: Why is this?
(A: The green clippings are made of iron and are therfore affected by the magnet and take on the pattern of its field of force.)

MAGNETIC PENDULUM: FURTHER INFORMATION

Magnets
A magnet has a north or south pole at its ends. Two similar poles repel each other but a north and south pole attract. Ring magnets have north or south poles on their opposite faces. The force is only felt over a relatively short distance and is strongest close to the magnets. (The force is inversely proportional to the square of the distance.)

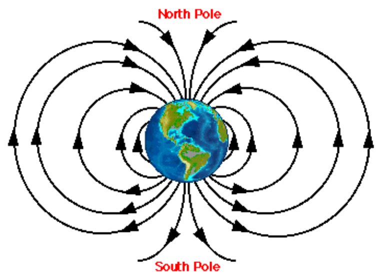


The magnet in the pendulum has been arranged so that the magnets in the discs will repel it. The result is that it will swing away before coming into the field of another magnet.

Chaos
Although we might be able to calculate any particular force at a precise moment the series of minute variations by the swinging magnet in response to those forces would make it impossible to predict its position more than a short timt ahead. Similarly, weather systems can be difficult to predict. Obviously if you have heavy rain west of London and strong westerly winds you can predict the weather shortly to arrive in the centre of the city. But further in advance a whole numbers of factors have to taken into account. Tiny causes may have great consequences: the flapping of a butterfly's wings in the Gobi Desert may cause a tornado in Kansas for Dorothy.

Magnetic fields
The field of force surrounding a magnet is normally invisible. It can be shown by placing small pieces of iron, like filings or clippings around the magnet. With a bar magnet the field passes in an arc between the poles at either end. The magnetic field of a ring or annular magnet with its poles on each face makes the clippings stand up in a circle.

The Earth is a giant magnet
The Earth itself is a giant magnet though not very strong, so we are surrounded by magnetic fields. This is why a compass can tell us the direction of north.



STRUCTURES

Making buildings or other structures requires an understanding of the forces involved

DESCRIPTION
RIGHT: Wooden blocks.can be constructed to make an arch bridge across fixed points.

LEFT: A square structure can be examined for its rigidity with and without a cross-strut.

CURRICULUM LINKS
Key stage 1
“They should... experience the natural force of gravity pulling things down.”
Key stage 2
“Pupils should explore different types of forces including gravity... This work should be set in everyday situations...”
Key stage 3
“Pupils should investigate ... the stability of everyday objects...”

RELATED EXHIBITS
Centre of gravity
This exhibit explores the significance of gravity.

WHAT TO DO
RIGHT: Use the wooden blocks to create an arch that spans the gap between the two fixed blocks. It helps to have more than one person doing this.

Q: Why does it stand up?
(A: The downward force of gravity on each block is directed sideways to the outside blocks (1 & 7) fixed to the base.)

Q: Where is the strongest point in the span?
(A: The central block (4) – the keystone. If you push down firmly on it the bridge won’t fall down. Strong pressure on a side block may cause collapse.)

OTHER THINGS TO DO
Look at the arches in bridges and old churches to see arches. The problem for a building is securing the sides. With the high walls of a church there is great sideways pressure which can cause the walls to push outwards bringing down the roof. Great weight or buttresses must be added to keep the roof aloft.

LEFT: Disconnect the cross-strut and push on the sides of the square metal structure.

Q: Is the structure rigid?
(A: No. Even making the corner screws very tight would not give it real strength.)

Now fit the loose bar diagonally across the square and screw on the knob.

Q: What difference does this make?
(A: The structure is now totally rigid. This is known as triangulation. It is the single most important factor in simple construction.)

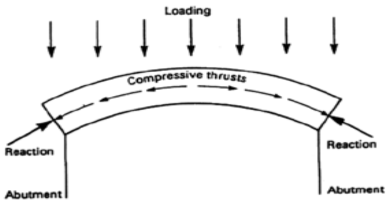
OTHER THINGS TO DO
Look at structures such as roof beams and truss bridges to observe triangulation.

STRUCTURES: FURTHER INFORMATION

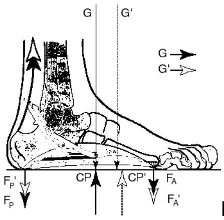
Structures
Materials behave differently in their response to forces. Some materials will bend, twist or squash easily but others such as steel require a much bigger force to produce a change.

The shape of a structure is as important as the material it is made from and even quite weak materials such as newspaper can be made very strong if they are rolled into tight tubes, for instance.

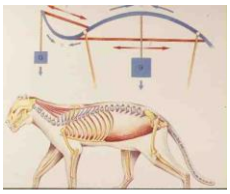
Arches
Structures are designed so the forces are deflected along to the strongest part. Bridges are a good example. In an arch bridge the force of the weight of a lorry is deflected sideways and down through the blocks to the abutments which are firmly fixed to the ground. The arch is made of solid blocks which are very strong.



Skeletons
Skeletons make use of such an arrangement, e.g. in the arch of the human foot or the backbone of most four-legged vertebrates. In ourselves the spine has had to be adapted to the upright position, forming an S-shape. This not a strong structure which why such a high proportion of people suffer from bad backs. This is the problem with evolution - it did not start from scratch but adapted what was available. Any intelligent designer would have put the spine down the middle of the torso and slung the organs around it.



Human foot


Cat


Human spine

Triangulation
The cross-strut that creates a triangle is of fundamental importance in many structures. If you look at a truss bridge you will see that in effect it is made of a series of triangles. It can use much less material relying on these shapes to give it its strength. If squares were used instead of triangles the bridge would simply collapse.


Truss bridge